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RESEARCH MEMORANDUM

A PRELIMINARY INVESTIGATION OF SHOCK-WAVE REFLECTIONS IN A SMALL CLOSED BALLISTIC RANGE WITH VARIOUS TYPES OF WALLS

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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A PRELIMINARY INVESTIGATION OF SHOCK-WAVE REFLECTIONS IN A SMALL CLOSED BALLISTIC RANGE WITH VARIOUS TYPES OF WALLS

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SUMMARY

A preliminary study has been made of several types of walls that might be used to minimize shock-wave reflections for bodies traveling at low supersonic speeds in a small ballistic range. Results are presented in the form of shadowgraphs and schlieren photographs. The reflected shock waves were found to be greatly reduced by the use of a material having good sound-absorbing characteristics or by wall configurations having faired slots alone or faired slots with concave channels.

INTRODUCTION

One of the problems associated with the development of closed ballistic ranges or wind-tunnel throats for transonic research is that of eliminating or minimizing the reflection of shock waves from the wall to the model. During the course of preliminary studies of transonic test sections, the effectiveness of various wall configurations in eliminating reflections in a small ballistic range was investigated. The purpose of the present paper is to present the results of this investigation in the form of shadowgraphs and schlieren photographs.

Attention is called to the fact that the reflection problems in the slotted ballistic range do not correspond directly to the transonic tunnel problems, since a disturbance reaching a slot in a slotted ballistic range is propagated outward without change; whereas, in the wind tunnel the slots are free boundaries separating a stream of high velocity from still air. From such a boundary, incident disturbances are reflected with a reversal in sign.

APPARATUS AND METHOD

The apparatus used in this investigation is schematically presented in figure 1. Commercially available bullets were fired from a standard .22-caliber rifle to create shock waves. The bullets were directed over the wall configuration to be tested. Varying the choice of ammunition provided a range of 0.946 to 1.161 in the free-air bullet Mach number.

The Mach number M of the bullet was determined by the same procedure for all tests. During the bullet flight, it punctured two sets of aluminum-foil screens 64 inches apart stationed on either side of the test section. The time elapsed between screen contacts was recorded by an electrical chronograph whose resolution was ±10 microseconds. An inaccuracy in spacing of the foil screens was ±1/16 inch which represents a time of flight variation of ±4.5 microseconds for a typical bullet velocity of 1130 feet per second; hence, the actual projectile velocity could be obtained to within ±3.5 feet per second. The speed of sound was obtained by calculation from the measured value of the ambient temperature which was measured to within ±1° F.

The wave pattern set up by the bullet was recorded photographically by a parallel-light shadowgraph method or by a schlieren system. A crystal microphone was placed near the line of flight to detect the pressure wave associated with the bullet, whence the signal was amplified to trip a spark light source that was used in both optical systems. By proper location of the microphone, it was possible to make the records when the model was at approximately the center of the test section. The light from the point source was collimated by a parabolic reflector and covered a $5\frac{3}{4}$-inch circular field. A shadowgraph of the disturbance in the test section was made on a film placed 12 inches from the bullet path. A single traverse schlieren system was used to observe the same area of the wave pattern within the test section.

Prior to tests of the various wall configurations, tests were made to determine the wave pattern about the bullet traveling in free air. Tests were then made in a square closed-wall tube of constant cross section into which the bullet was fired. The surfaces under examination were upper and lower metal walls, and glass windows served as the side walls. The working length of the walls was 11 inches. The ratio of the maximum cross-sectional area of the bullet to that of the square tunnel was arbitrarily made 1:100. Figures 2(a) and 2(b) illustrate similar tunnels with two types of slotted upper and lower walls that were used for testing. In each of these cases, the enclosed area was equal to that of the square closed-wall test section, and the ratio of the slotted opening to the solid-wall area was arbitrarily made 1:5.28.

In addition, tests were made of several curved wall designs, as illustrated in figure 3. For this group, the viewing windows were removed and the wall section was distributed along a circular arc of approximately 90°. Figures 3(a) and 3(b) picture curved wall designs consisting of a series of round rods that were separated to form slots having no abrupt discontinuities. The area ratio of the slotted openings to the solid wall width was made 1:5.28 and the distance from the wall to the bullet was arbitrarily selected. Another curved wall with slotted openings was made with lenticular bars (fig. 3(c)) designed to guide a wave disturbance from the working diameter of the section to the outside. A serrated perimeter was placed exterior to the slots further to confine the waves. The area ratio of the slotted openings to the solid wall was again 1:5.28 and the wall distance to the bullet path was arbitrarily selected.

A third curved-type test section was designed with a wave-trap type of wall that considered the geometry of a simple wave reflection phenomenon from a solid surface. Shock waves were made to fall into a longitudinal channel by making the contour of the channel sides approximately a parabolic arc (fig. 3(d)). A wall section was made (fig. 3(e)), which in addition to the concave channels contained slots having a smooth variation through the thickness of the wall.

Tests were made on flat metal wall configurations to determine the effect on the wave pattern of adding a sound-absorbing medium. Since cotton exhibits remarkable sound-wave absorbing properties, these walls were covered with short fibers of cotton (flock) and then with cotton batting. For purposes of comparison, tests were also made of several flat metal surfaces.

RESULTS AND DISCUSSION

The general nature of shock-wave patterns about a bullet when the accompanying waves are permitted to pass freely through air at Mach numbers from 0.946 to 1.076 is pictured in figure 4. The flow pattern of figure 4(a) was created by a bullet at a Mach number of 0.946. Over the forward part of the body, air is accelerated locally to supersonic Mach numbers and is recompressed through a series of shock waves which appear in these shadowgraphs as lines of dark and light composition. With increasing Mach number, as in figures 4(b), 4(c), and 4(d), the region disturbed by a wave at the rear of the bullet broadened beyond view, and at Mach number greater than one, a detached bow shock wave appeared (fig. 4(d)). Vertical lines ahead of the bullet at subsonic Mach numbers are attributed to the effects of the detonation of the gun powder escaping from the muzzle of the rifle.

The shadowgraphs of figure 5 show the shock patterns obtained when the bullet was fired through a closed tube of square cross section. As in the free-air tests, an indicated Mach number M_i has been obtained from the measured speed of the bullet and the speed of sound in the chamber prior to the entry of the bullet. In a closed ballistic range, as in a closed wind tunnel, wall-interference effects are encountered which at subsonic Mach numbers result in an increase in the effective Mach number of the bullet. This effect is shown qualitatively by comparison of figures 4(a) and 5(a), which were taken at identical indicated Mach numbers. In the free-air shadowgraph (fig. 4(a)) the shocks are confined to a region approximately two bullet diameters from the model; whereas, in the square closed section (fig. 5(a)) they reach the walls approximately five diameters away and are reflected rearward into the stream. In general, only the region downstream of the reflected shock will be influenced by it; however, if these disturbances pass through the subsonic wake of the bullet, they will exert an added pressure over its base. At supersonic speeds, the model is preceded by a shock which may, as in figure 5(c), be followed by subsonic air, in which case the disturbance reflected from the solid boundary is propagated throughout the field behind the bow shock so that the flow over the entire body is altered.

In order to reduce the intensity of the shock-wave reflections and to alleviate choking phenomena, longitudinal slots were incorporated into the upper and lower walls of the test section as shown in figure 2(a). The results of the bullet tests, illustrated in figures 6(a), 6(b), and 6(c), indicate that reflections are still returning to the bullet and to its wake; however, the shock reflections at the treated boundaries in each case are diminished in intensity, since a portion of the incident wave is free to extend outside the section as shown in figure 6(c). For the subsonic case, the interference of the slotted walls is still sufficient to cause the bullet to experience an effective greater Mach number flow.

Additional tests were made with pitched crowns on the bars separating the longitudinal slots as shown in figure 2(b) to help confine the incident shock disturbances to the wall. The test results appear in figure 7. Examination of these shadowgraphs indicates the presence of wave reflections, the origin of which appears to be within the wall depth where the shape of the slot changes abruptly. A comparison of figures 6(c) and 7(c) qualitatively shows that the pitched-crown configuration mitigates the reflected wave more than the straight slotted wall. It does not, however, affect the flow about the bullet enough to reproduce the conditions of free space. (See fig. 4(d).)

In shadowgraphs of figures 5(c), 6(c), and 7(c) white lines connecting the ends of the bow shock will be noticed in the test section at the front of the bullet. These lines were caused by the reflection of the bow wave at the windows, as is seen by comparing the shadowgraphs with figures 8 and 9, where no windows were present. Figure 6(c) shows two such lines, which indicate that the bullet is nearer one window of the test section.

The problem of shock reflections from curved walls was also considered in various wall configurations (fig. 3). The flow patterns for two curved wall sections formed by circular bars of different diameter (figs. 3(a) and 3(b)) show that shock reflections from the tops of the rods are present and they do reach back to the bullet and its wake (figs. 8 and 9). For this type of open configuration, the choking phenomenon is no longer present.

Figures 10(a) and 10(b) show the effects of using a curved wall section formed from lenticular bars (fig. 3(c)) on the shock reflections. A comparison of the wave pattern near the wall in these photographs with the free-air results of figure 4(d) shows no change in the shock pattern. In the schlieren photograph of figure 10(b), two dark lines appearing as arcs at the rear of the bullet are interpreted as disturbances created by the abrupt discontinuity at the entrance of the test section. Other darkened areas obliquely inclined behind the bow wave represent the reflections from the top of the incomplete slotted wall.

The results obtained with a curved wall with concave channels and unfaired slots (fig. 3(d)) are presented in figure 11(a). These results illustrate that the effectiveness of the wall is not enough to prohibit the reflections of waves which appear to originate in the wall depth, possibily at point A, figure 3(d). A test of this configuration was made with cotton batting stuffed against the opening at point A and the results (fig. 11(b)) show no visible reflections. The results of the test for the concave channels with faired slots (fig. 12) show a wall effectiveness comparable to that of the lenticular bars shown in figure 10(b), although reflections of a small intensity are detected.

Figures 13(a) and 13(b) show wave patterns about a bullet passing an untreated flat metal surface. Results for this flat surface with a velvet-like finish of cotton fibers (flock) are shown in figure 14. Comparison of the wave pattern in the vicinity of the wall with that of an untreated surface (fig. 13(a)) shows no substantial reduction in intensity of the reflected wave. When the thickness of the cotton was increased to approximately three quarters inch, loosely placed on the surface, comparison with figure 13 shows that complete elimination of reflected shocks appears to have been obtained (fig. 15).

CONCLUSIONS

The following conclusions are indicated from the results of this study of wave reflections for bodies traveling at low supersonic speeds in a ballistic range having various types of walls:

1. The use of walls with slots having abrupt discontinuities in contour were ineffective in eliminating shock-wave reflections.

2. The strength of the reflected shock was sharply reduced by the use of walls with faired slots and by the use of walls with concave channels and slots.

3. The shock-wave reflections were greatly reduced by the use of walls having good sound-absorbing characteristics, such as cotton batting; however, the use of cotton fiber (flock) when applied to solid walls was not effective.

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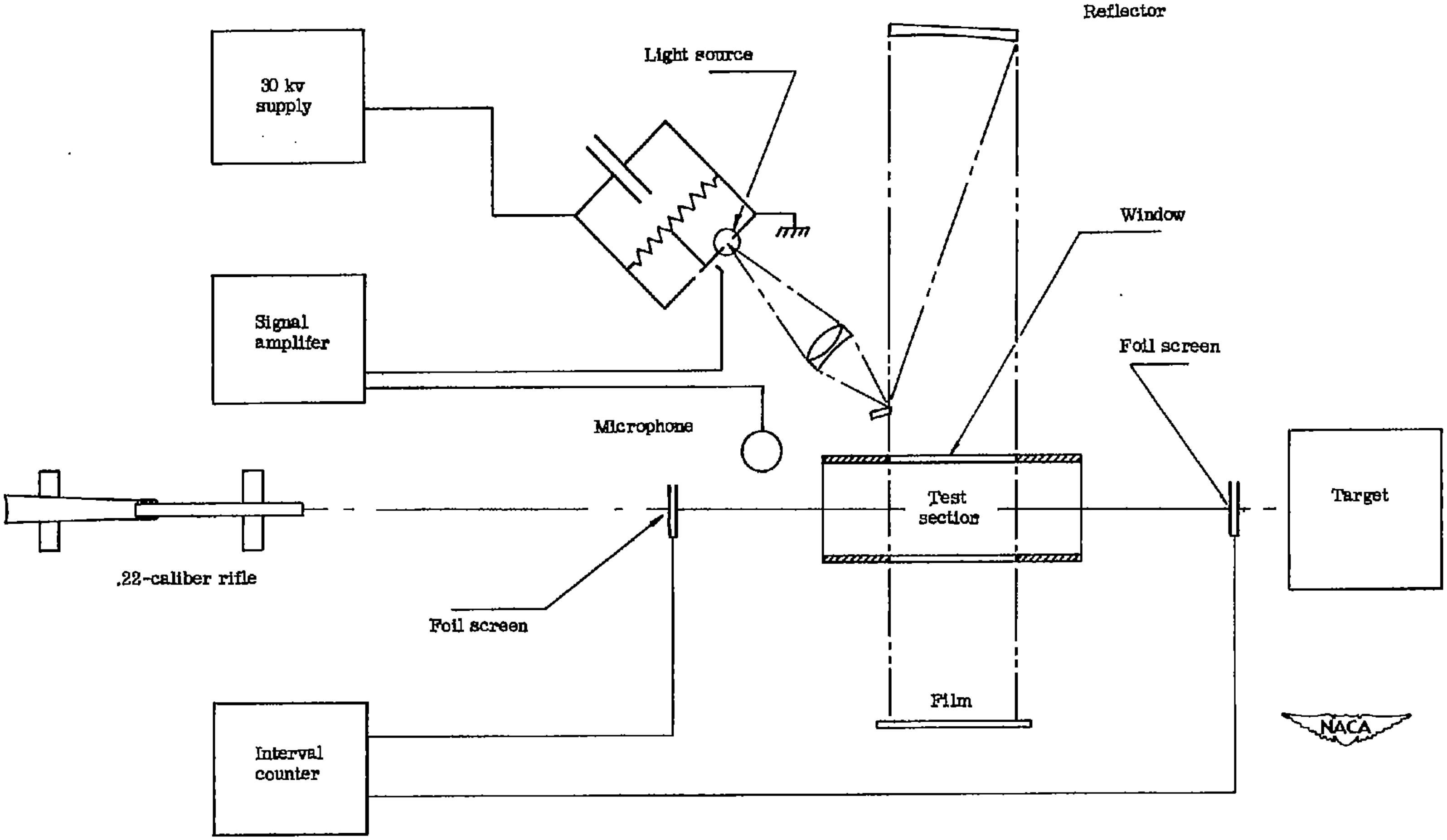

Figure 1.- Apparatus for observing wave-reflection characteristics.

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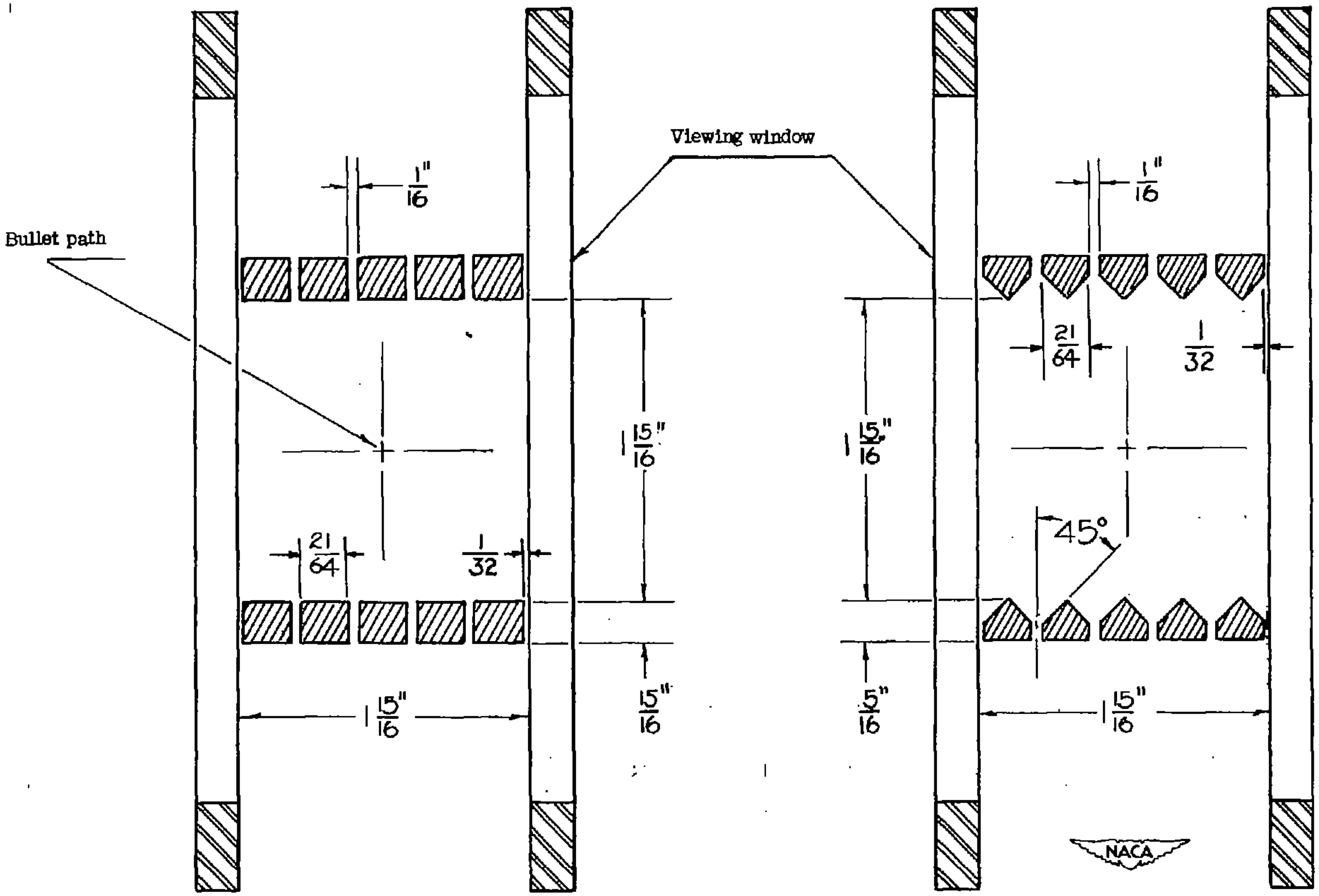

(a) Walls of flat slots.

(b) Walls of pitched slots.

Figure 2.- Cross-sectional views of slotted square test sections.

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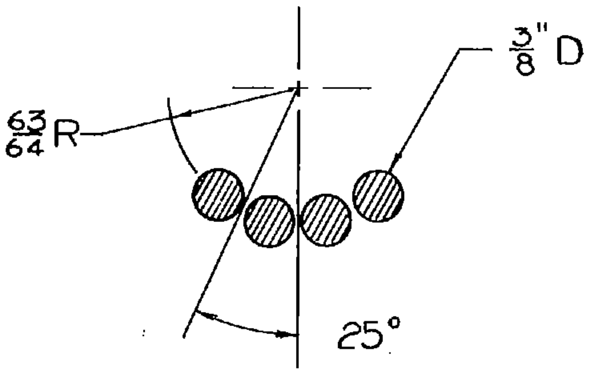
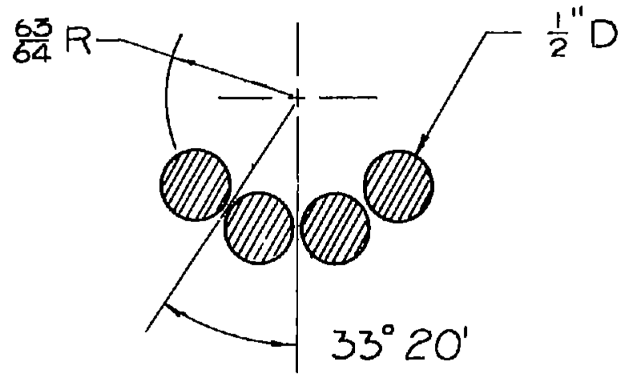
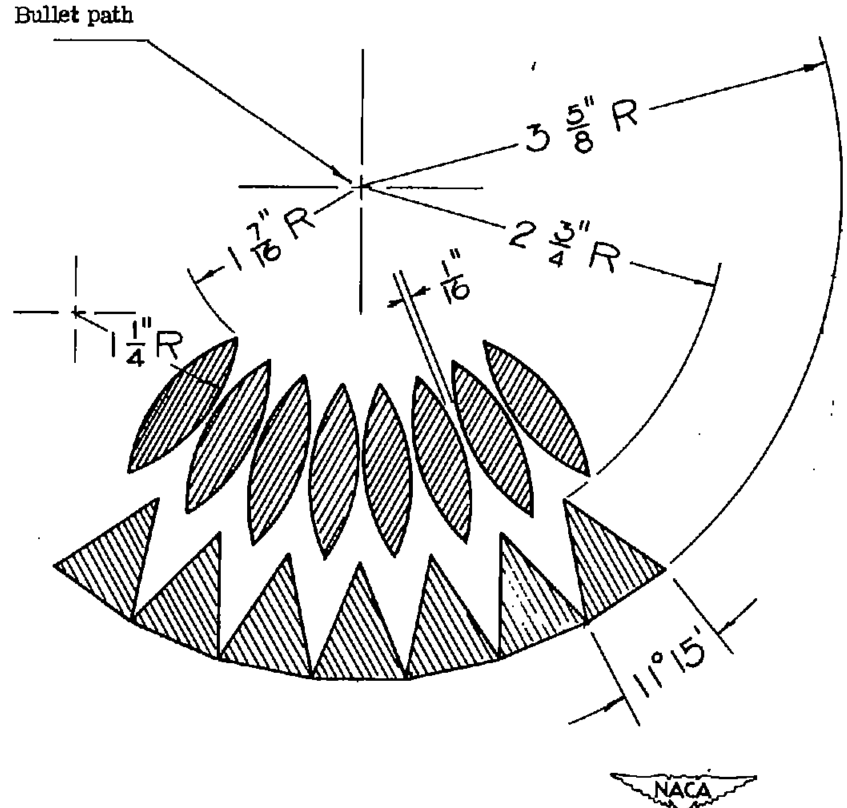


(a) Bars of $\frac{3}{8}$-inch diameter.

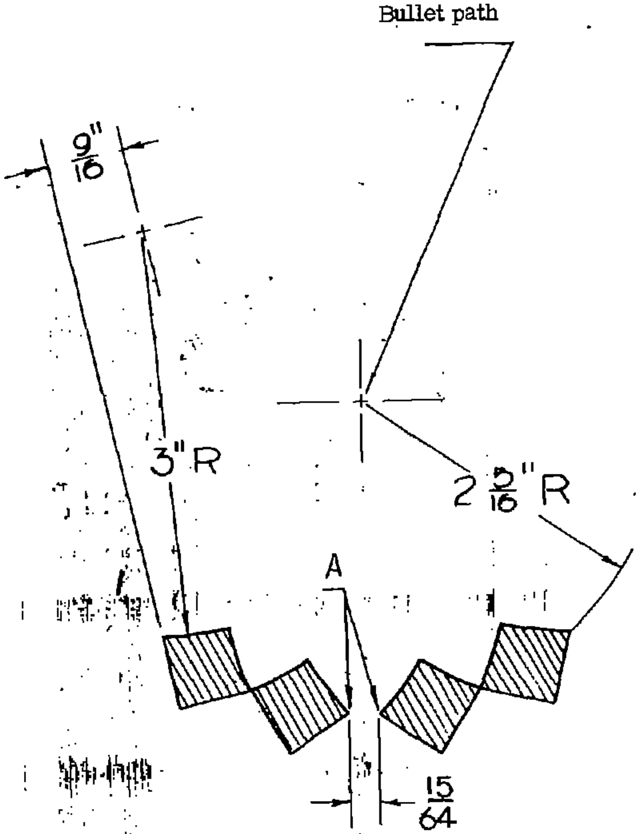


(b) Bars of $\frac{1}{2}$-inch diameter.

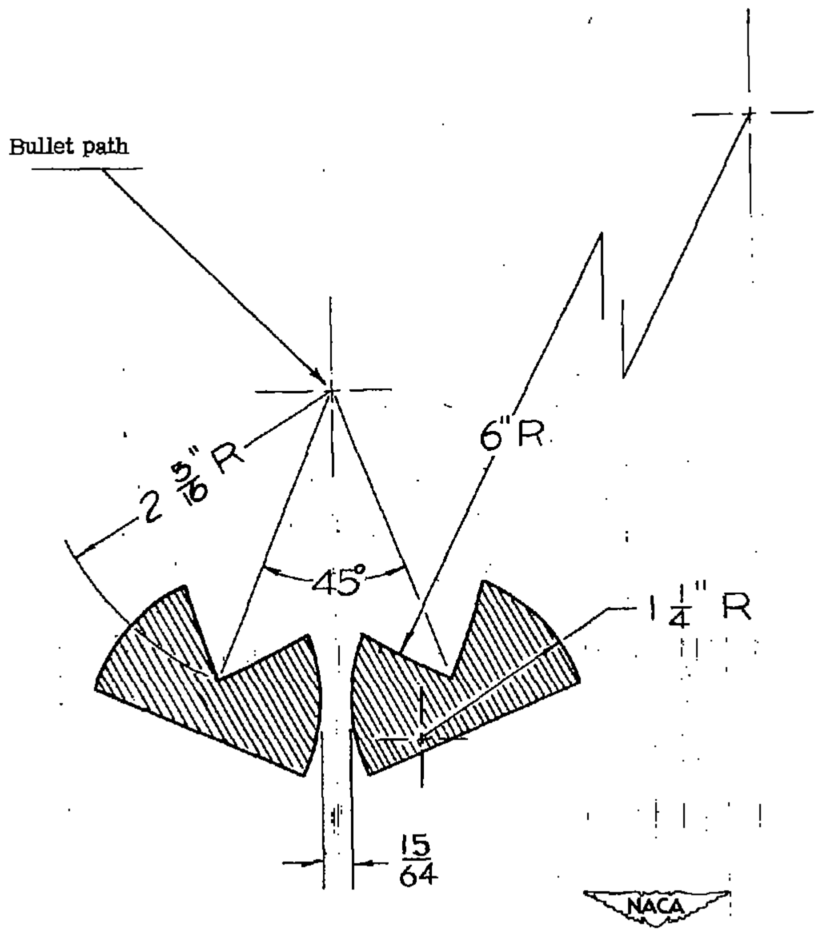


(c) Lenticular bars.

Figure 3.- Cross-sectional views of curved test-section walls.

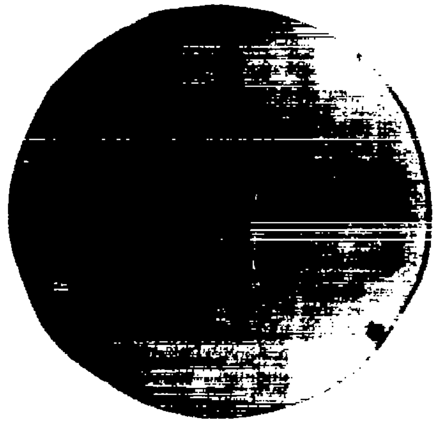


(d) Concave channels with unfaired slot.

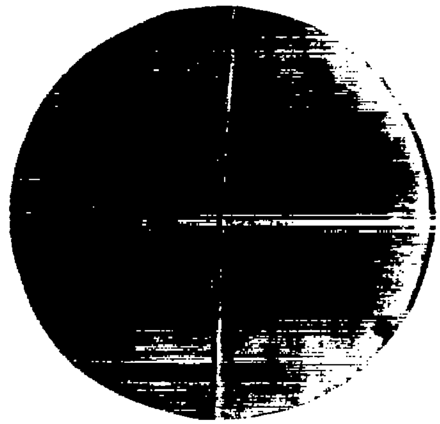


(e) Concave channels with faired slot.

Figure 3.- Concluded.



(a) M = 0.946.



(b) M = 0.979.

(c) M = 1.004.

(d) M = 1.076.

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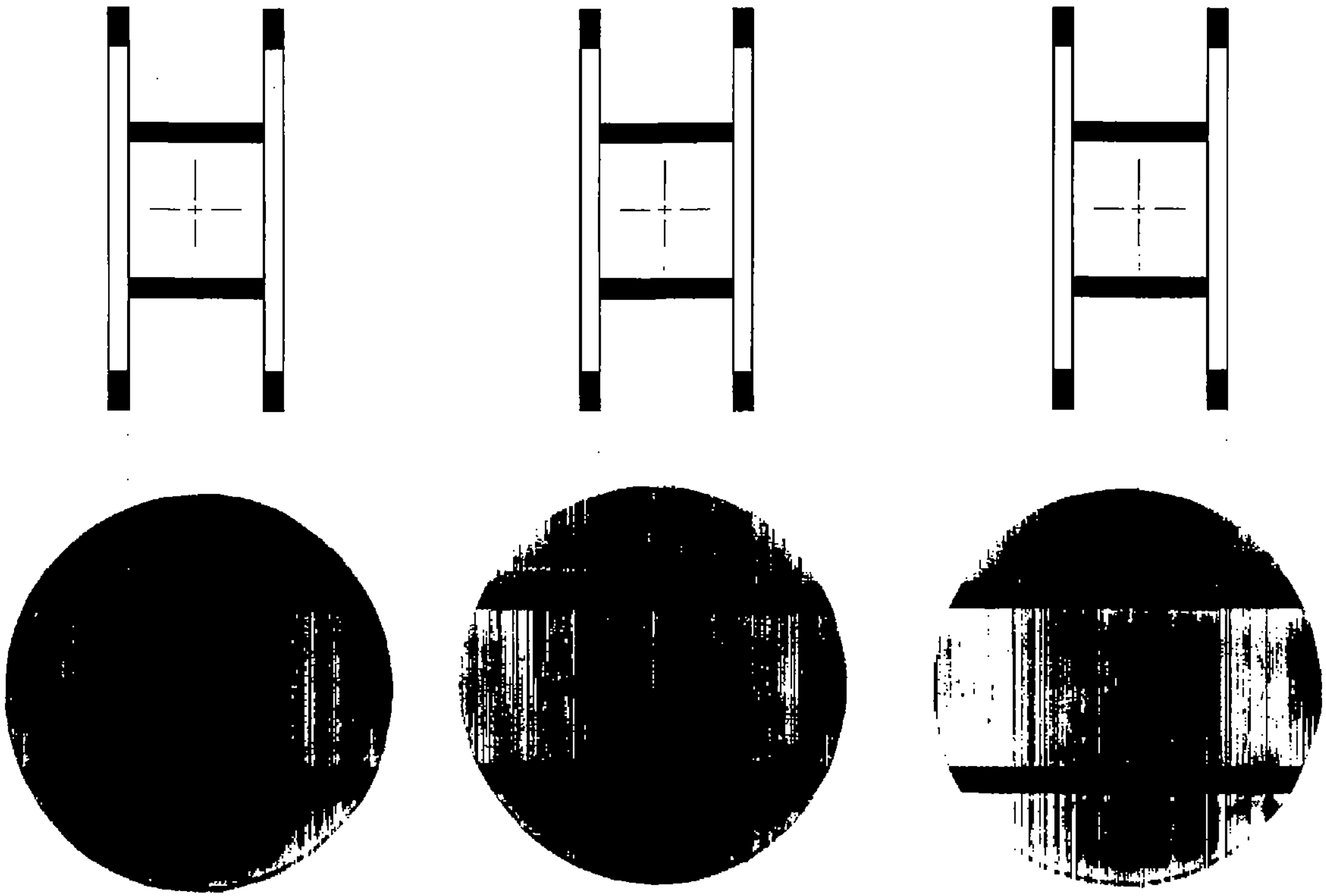
Figure 4.- Shadowgraphs of bullet in free space.



(a) $M_1 = 0.946$. (b) $M_1 = 0.997$. (c) $M_1 = 1.093$.

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Figure 5.- Shadowgraphs of bullet passing through square closed section.

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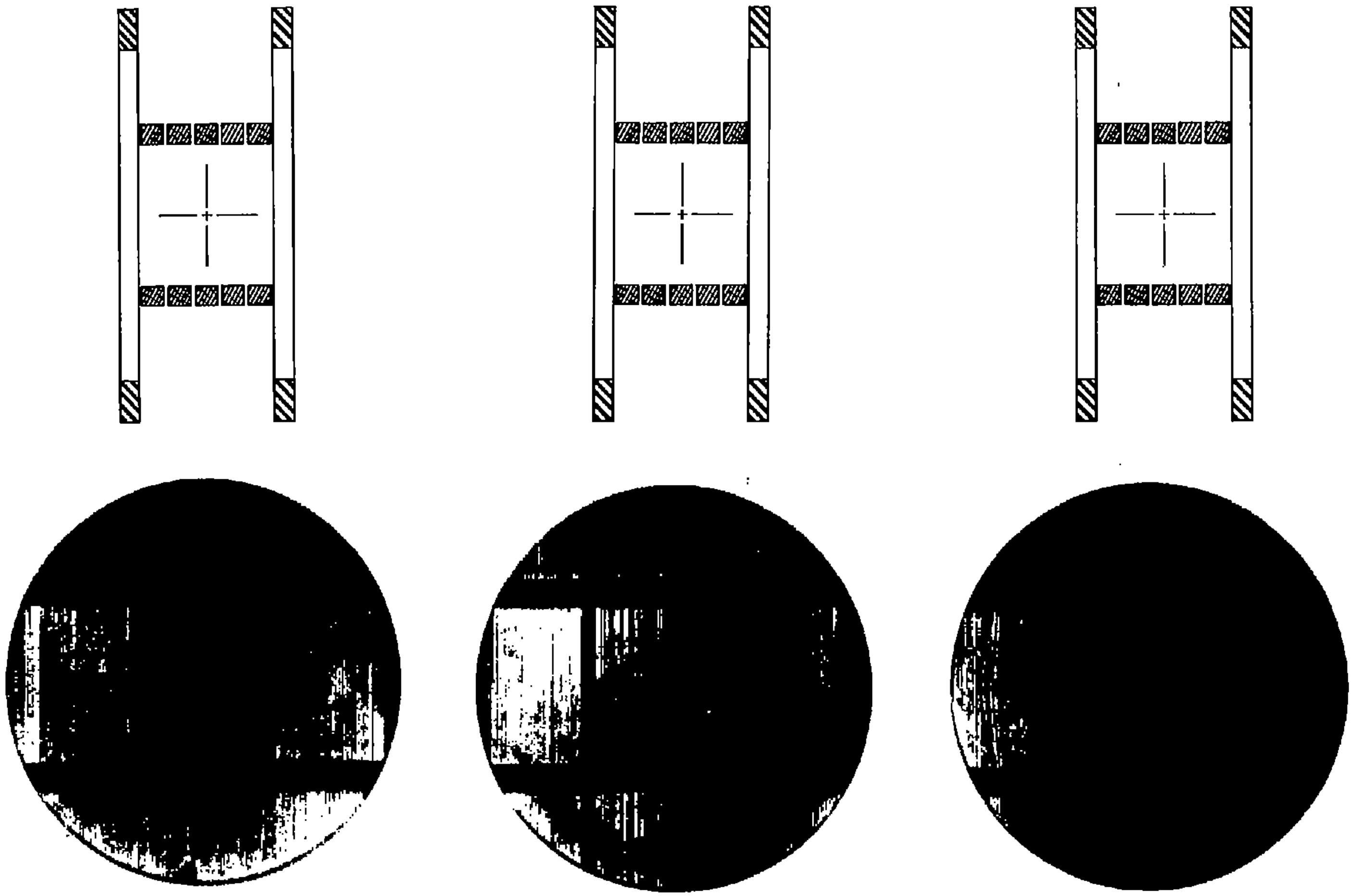

(a) $M_i = 0.939$. (b) $M_i = 0.994$. (c) $M_i = 1.100$.

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Figure 6.- Shadowgraphs of bullet passing through square section with flat slotted walls.

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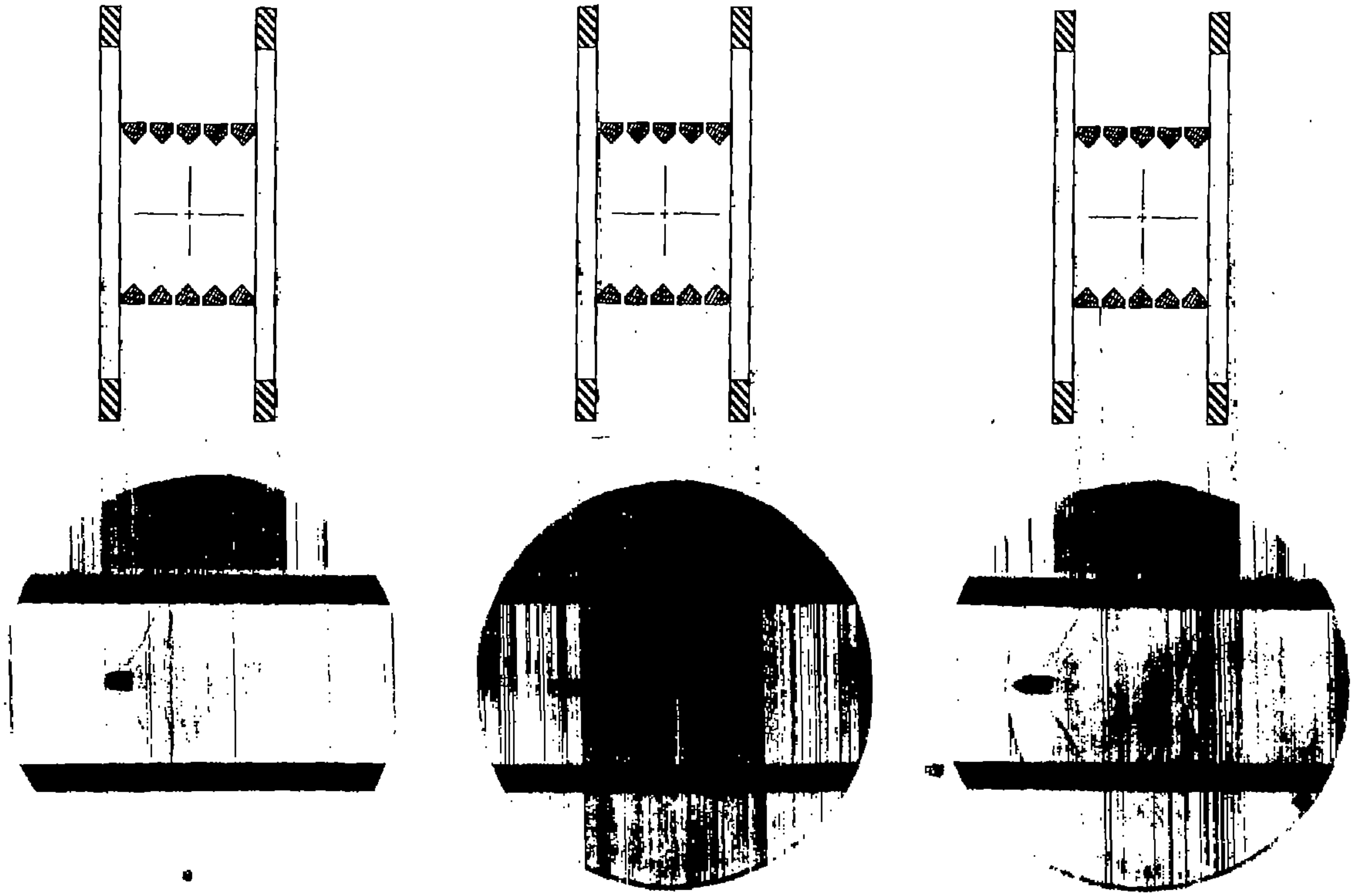

(a) $M_1 = 0.995$. (b) $M_1 = 1.007$. (c) $M_1 = 1.135$.

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Figure 7.- Shadowgraphs of bullet passing through square section with pitched slotted walls.

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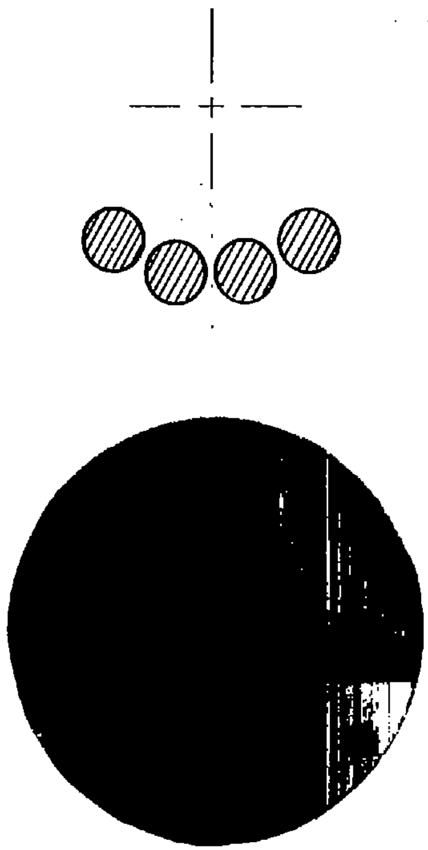

Figure 8.- Shadowgraph of bullet passing curved section formed by $\frac{3}{8}$ - inch-diameter bars. $M_i = 1.145$.

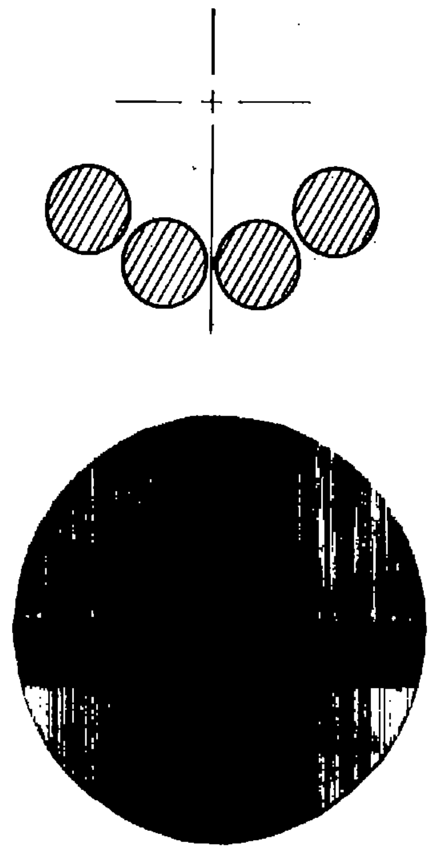

Figure 9.- Shadowgraph of bullet passing curved section formed by $\frac{1}{2}$ - inch-diameter bars. $M_i = 1.161$.

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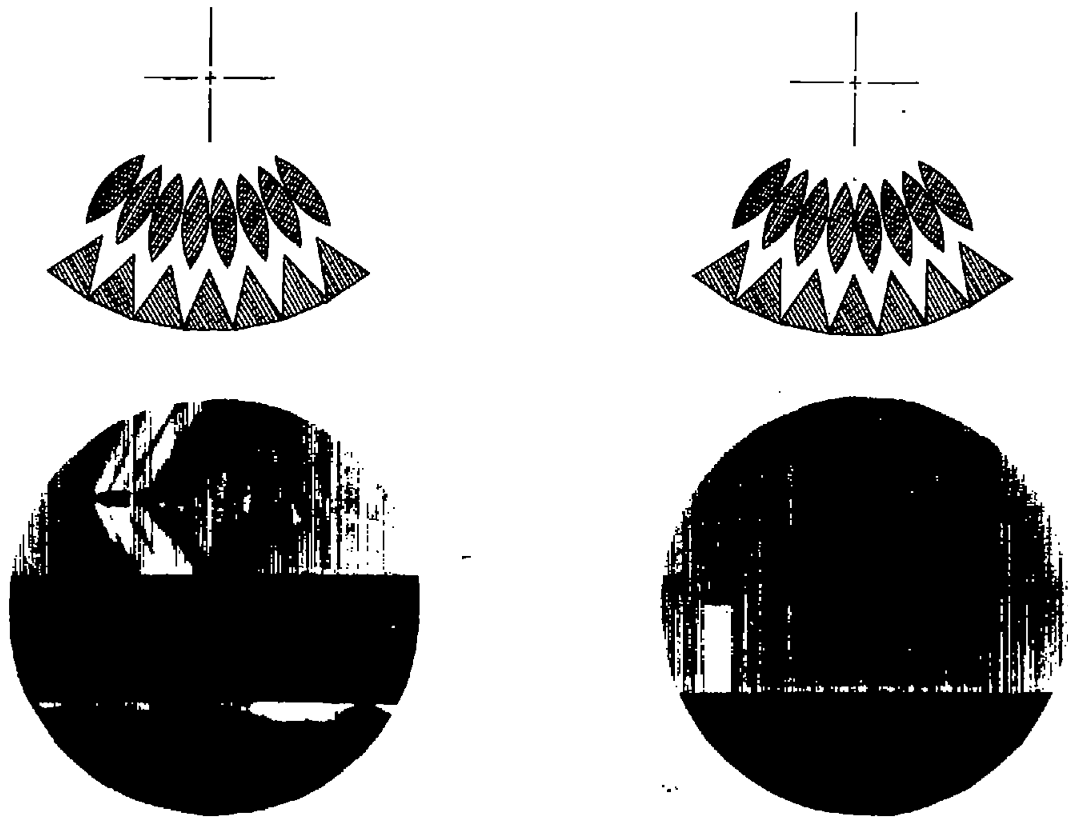

(a) Schlieren photograph.

(b) Shadowgraph.

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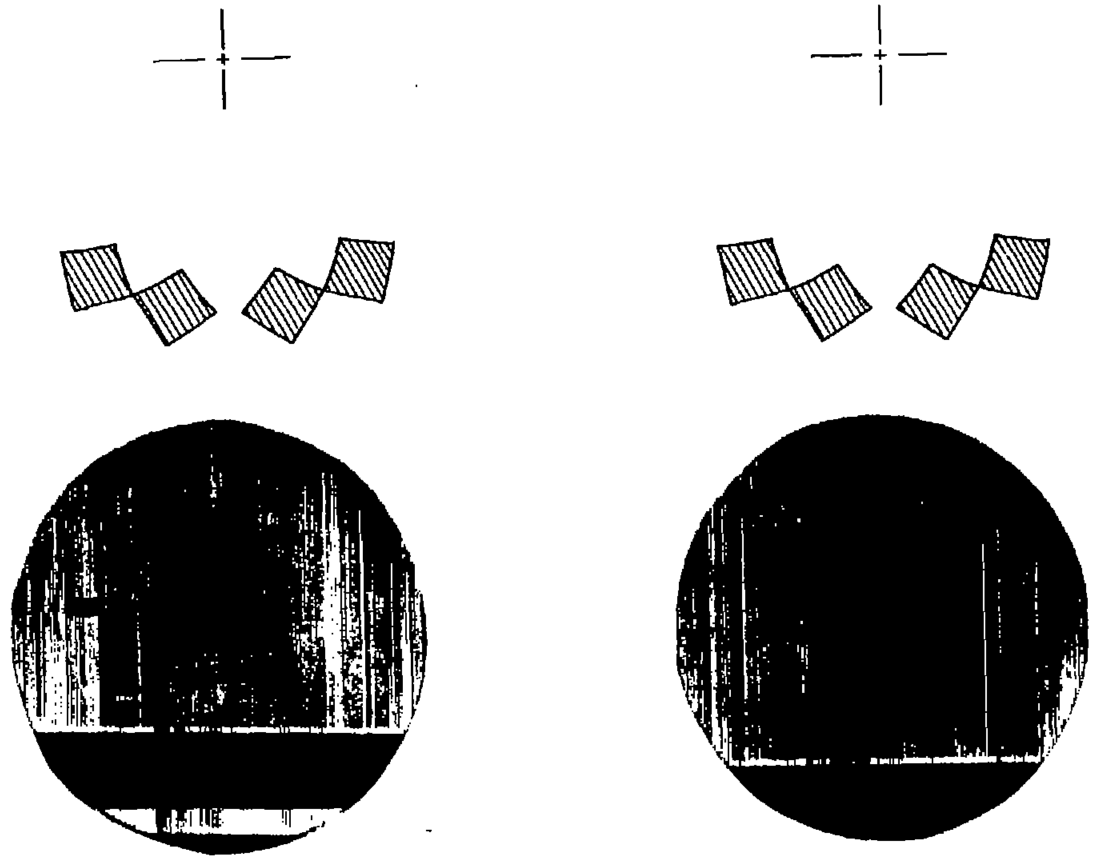
Figure 10.- Flow patterns about bullet passing curved section formed by lenticular bars. $M_1 = 1.141$.



(a) Slot open. $M_i = 1.160$.

(b) Slot stuffed with cotton. $M_i = 1.140$.

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Figure 11.- Shadowgraphs of bullet passing curved section with concave channel and unfaired slots.

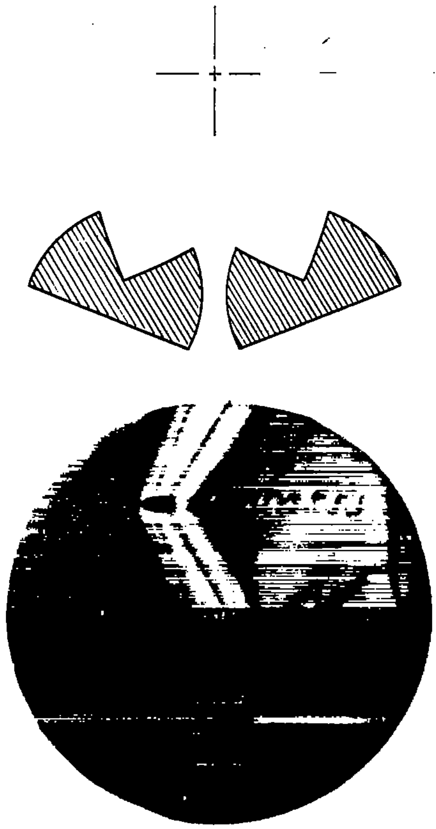

Figure 12.- Schlieren photograph of bullet passing curved section with concave channel and faired slots. $M_1 = 1.115$.

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(a) Shadowgraph. $M_1 = 1.129$. (b) Schlieren photograph. $M_1 = 1.131$.

Figure 13.- Flow patterns of bullet passing untreated flat metal surface.

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Figure 14.- Shadowgraph of bullet passing flat fiber-coated (flock) surface. $M_1 = 1.129$.

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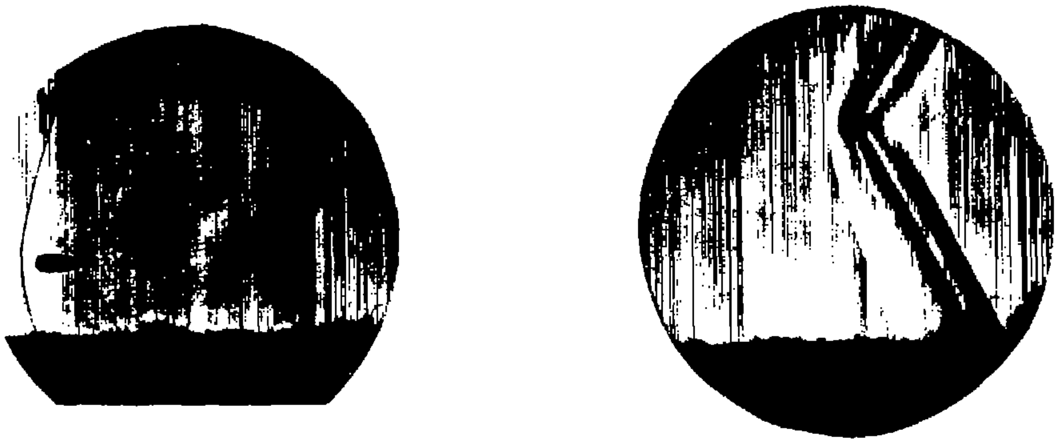

(a) Shadowgraph. $M_1 = 1.089$.

(b) Schlieren photograph. $M_1 = 1.128$.

Figure 15.- Flow patterns of bullet passing flat surface covered with $\frac{3}{4}$-inch cotton batting.

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